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Frantzen

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[54] **ENHANCED FLEXIBILITY SURGICAL STENT**

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[73] Assignee: **Global Therapeutics, Inc.**, Broomfield, Colo.

[21] Appl. No.: **874,975**

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[51] **Int. Cl.^{6}** **A61F 2/06**

[52] **U.S. Cl.** **623/1**

[58] **Field of Search** 623/1, 12; 606/192, 606/194, 195, 198

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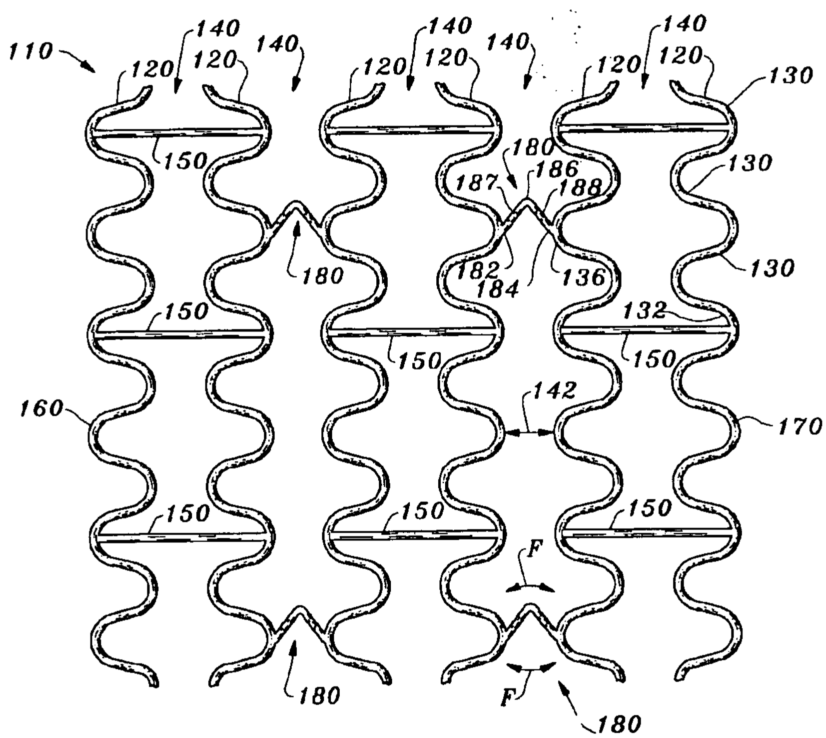
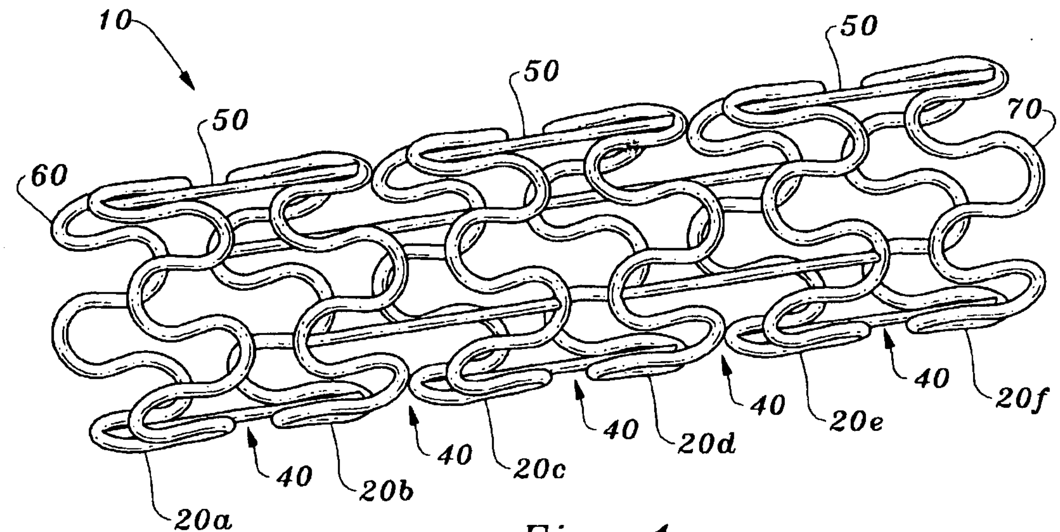
Primary Examiner—Mickey Yu
Assistant Examiner—John M. Black
Attorney, Agent, or Firm—Heisler & Associates

[57] **ABSTRACT**

A surgical stent (**10**) is provided which can be radially expanded away from a central axis (**2**) within a body lumen, such as an artery. The stent (**10**) is formed from a series of struts (**20**) circumscribing a cylindrical contour of the stent (**10**). Each strut (**20**) has a series of bends (**30**) formed therein with each bend including at least one trough (**32**) and at least one crest (**36**). Gaps (**40**) are provided between adjacent struts (**20**). Each gap (**40**) is spanned by an axial element such as a tie bar (**50**) or links (**180**). Each tie bar (**50**) attaches to adjacent struts (**20**) through troughs (**32**) so that when the stent (**10**) is radially expanded, the struts (**20**) are not drawn together, but rather maintain their position and the stent (**10**) hence maintains its axial length without contracting. Other elements such as the links (**180**) can be provided spanning the gaps (**140**) to provide enhanced flexibility for the surgical stent (**110**) including such links (**180**).

11 Claims, 10 Drawing Sheets

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20a
20b
20c
20d
20e
20f

Fig. 1

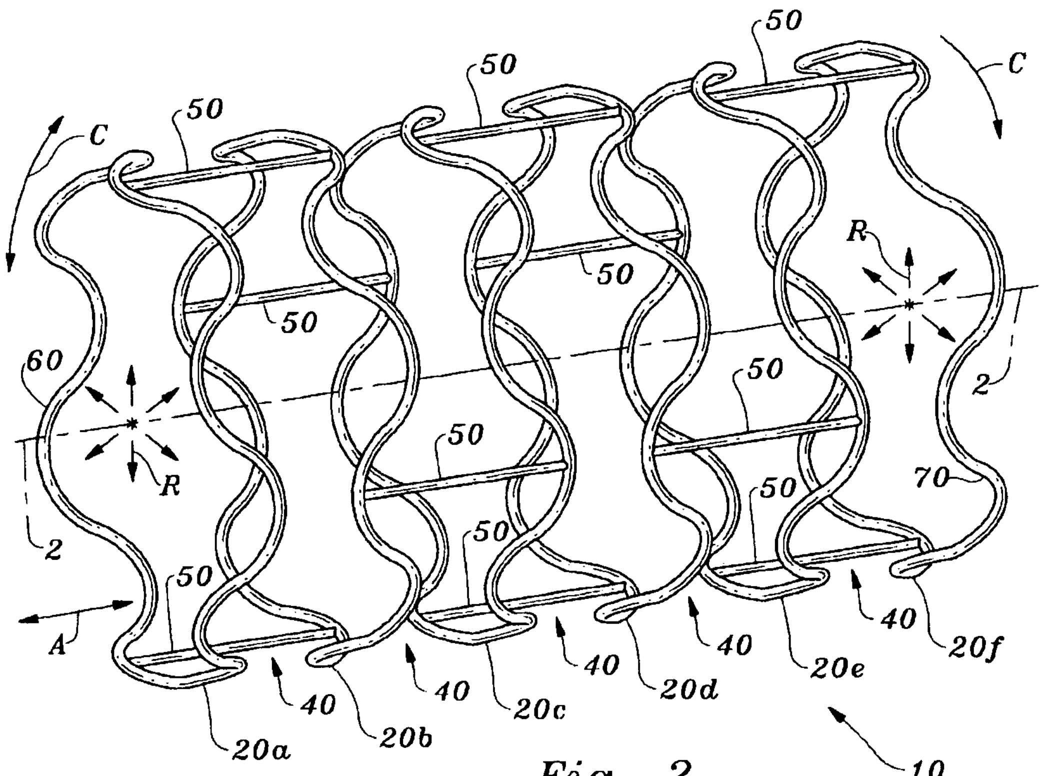
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Fig. 2

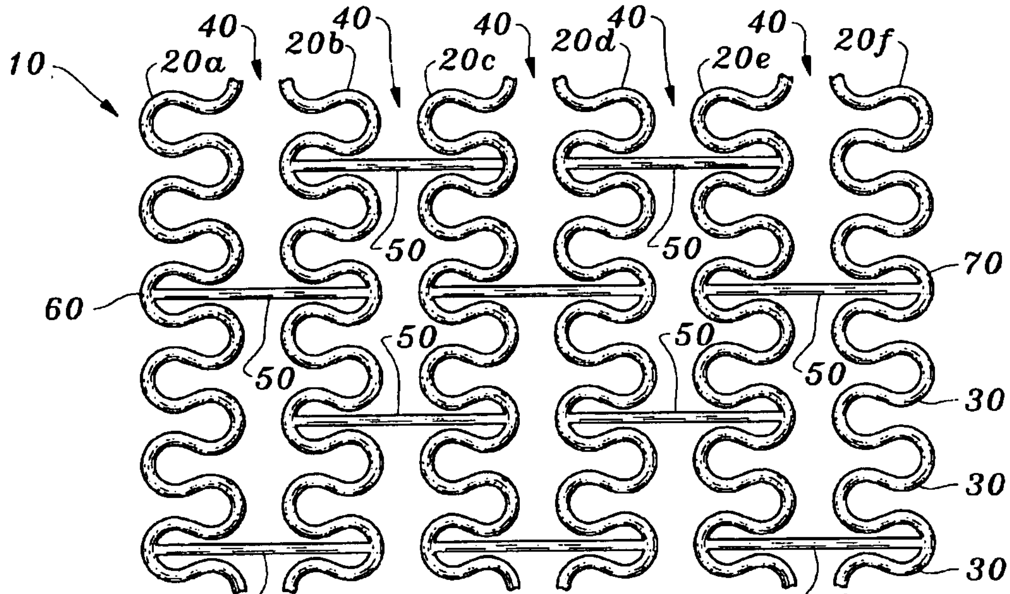
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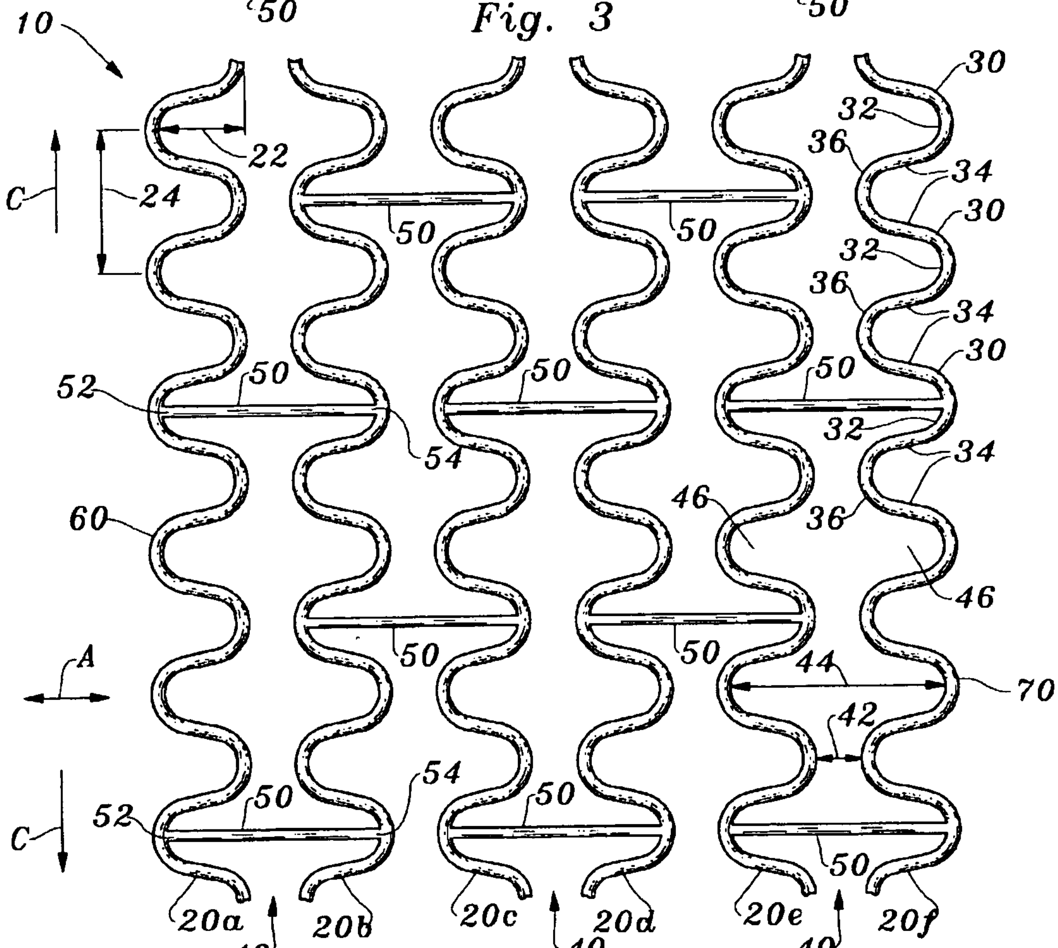
Fig. 3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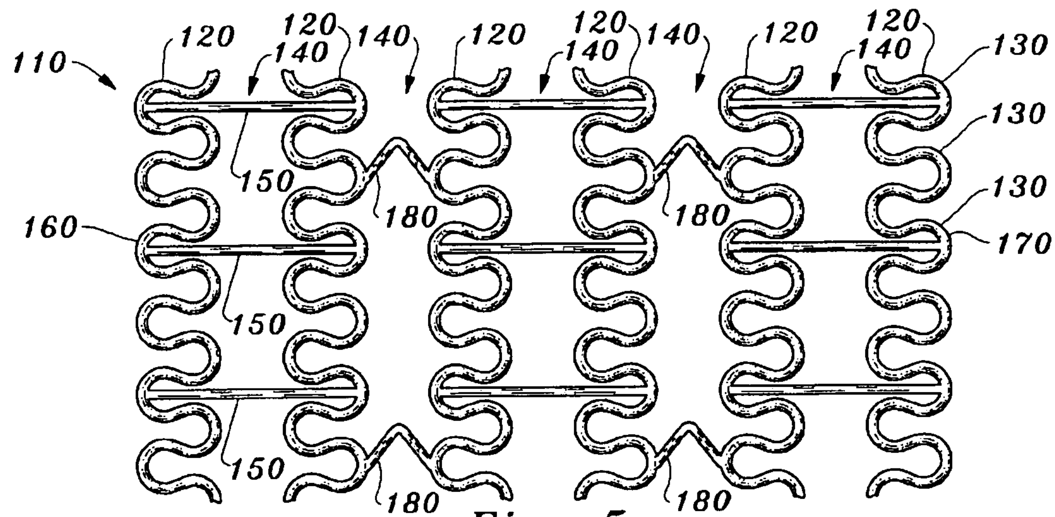
20d
20e
20f
40

Fig. 4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180
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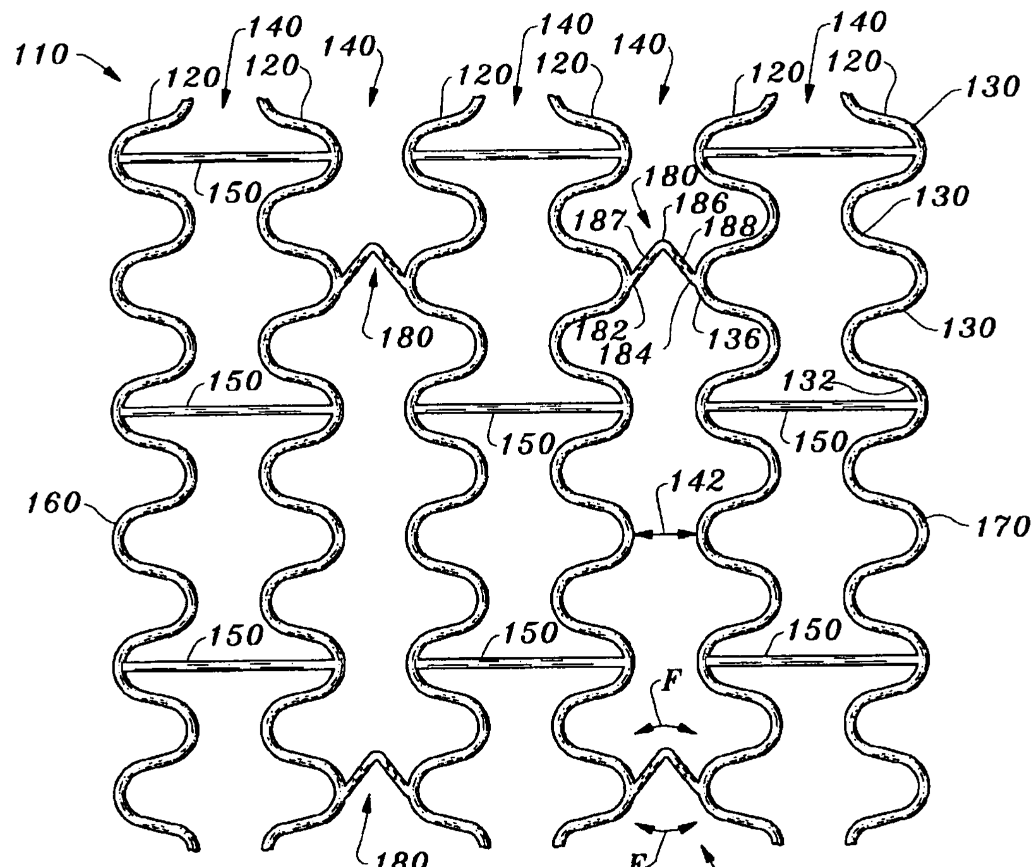
170

Fig. 5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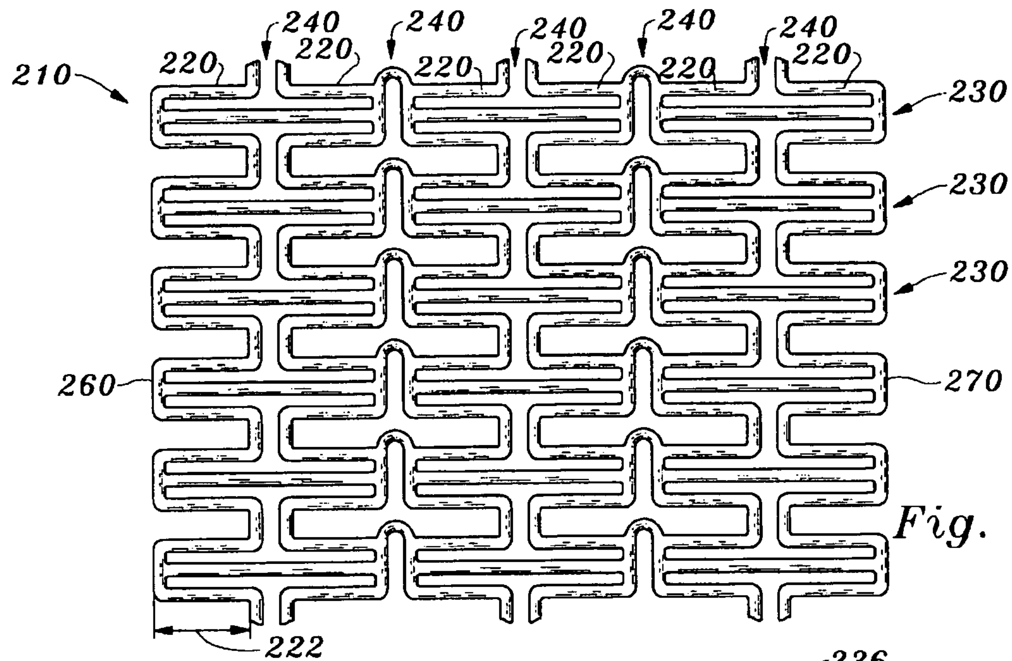
170
F

Fig. 6



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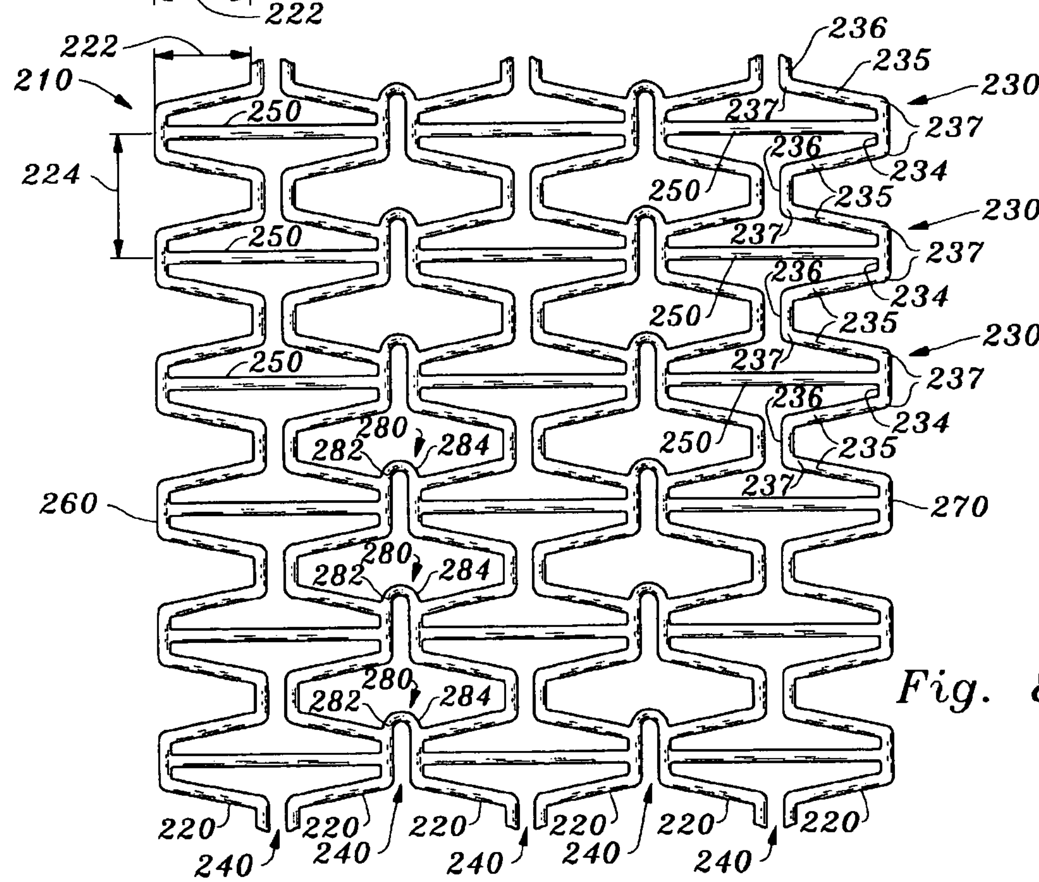
230
260
270

Fig. 7



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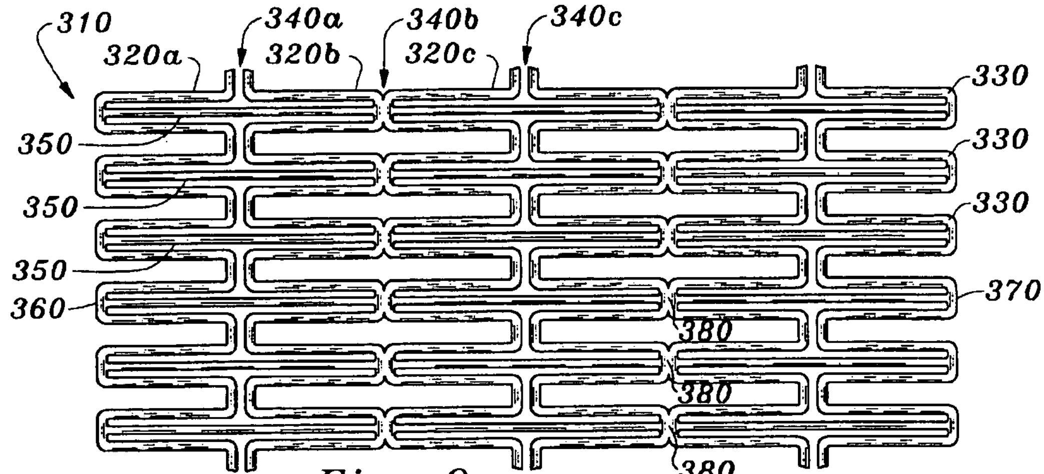
240

Fig. 8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340a
340b
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360
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380

Fig. 9

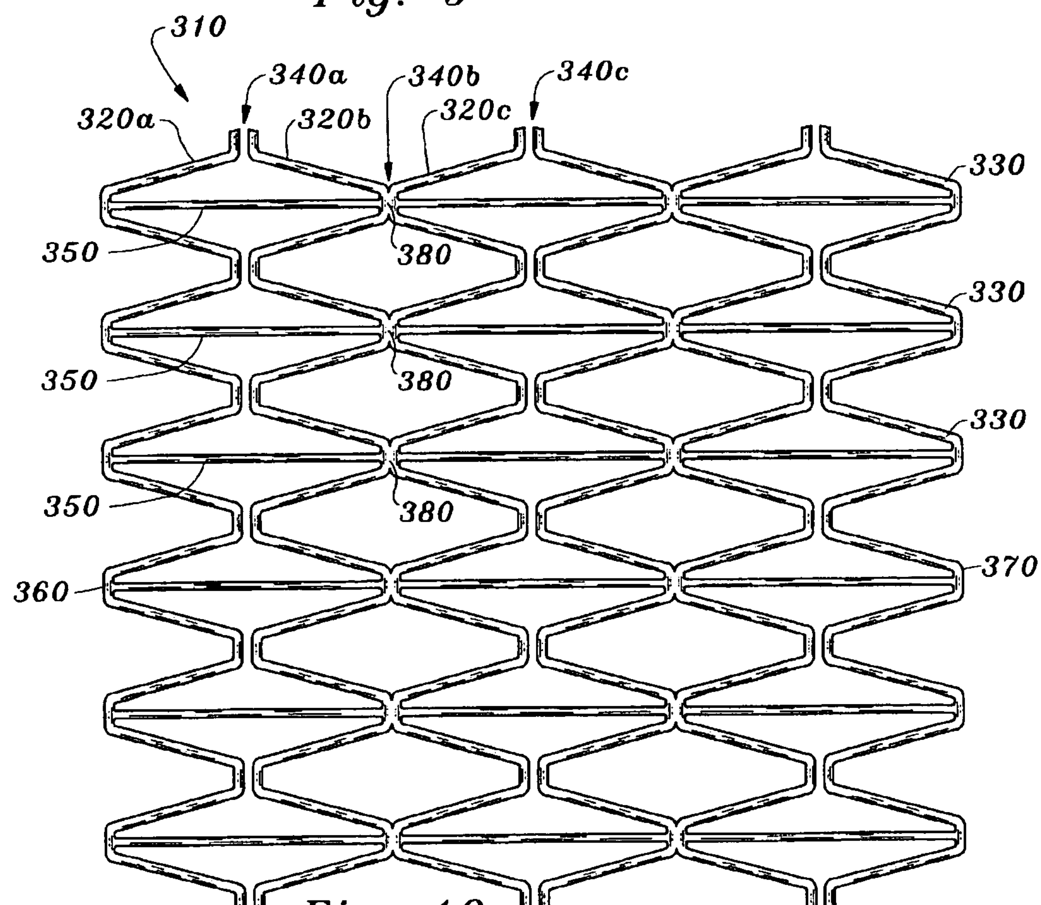
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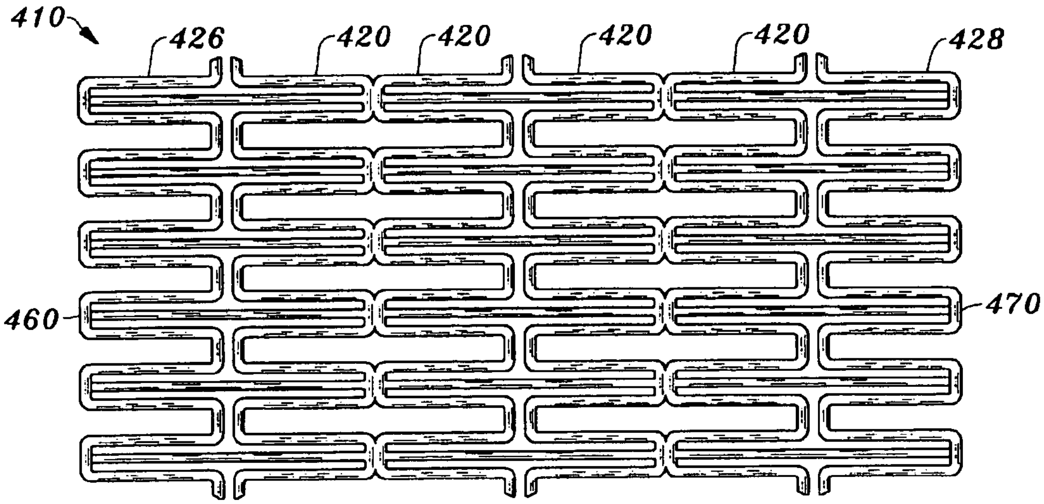
Fig. 10



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428
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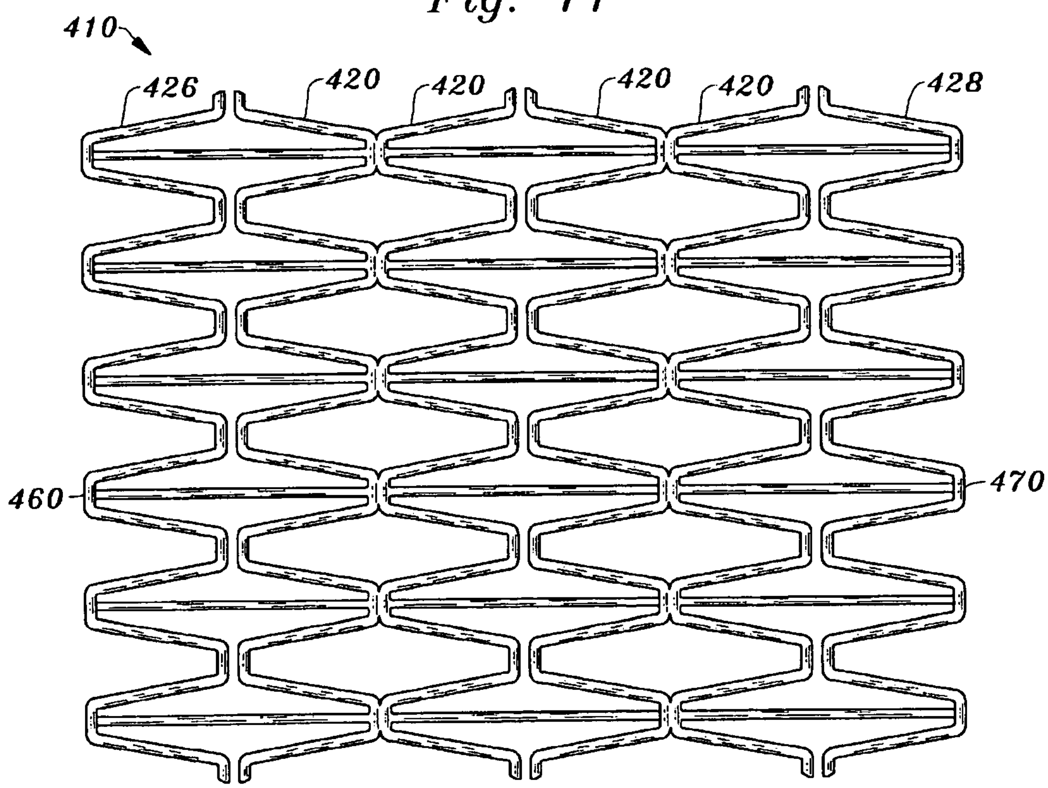
470

Fig. 11



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428
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Fig. 12

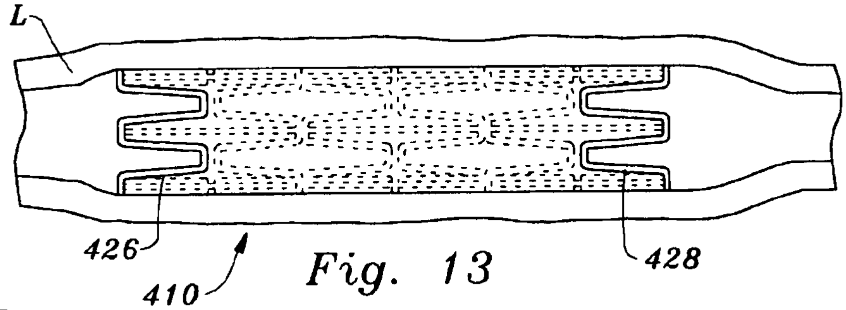


Fig. 13

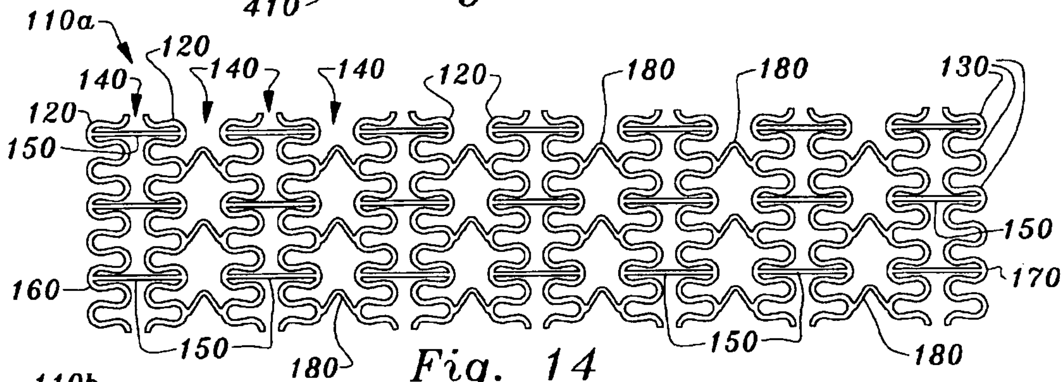
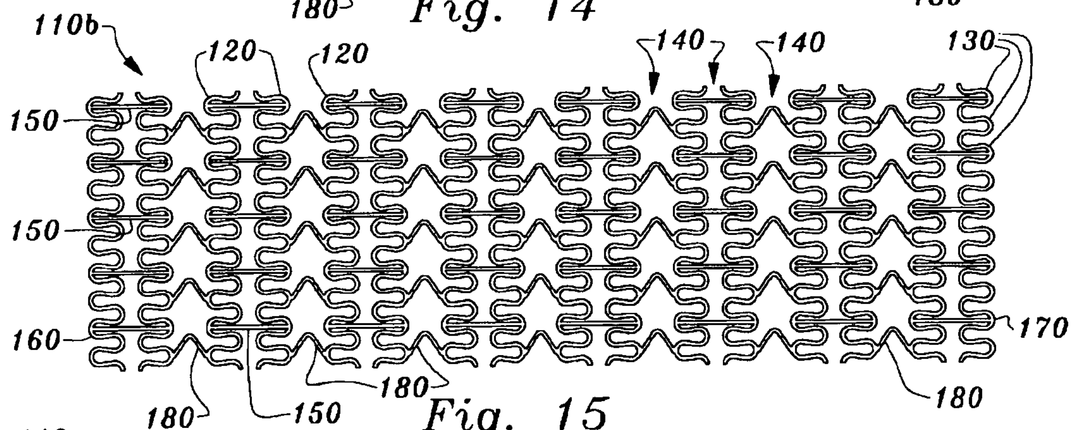


Fig. 14



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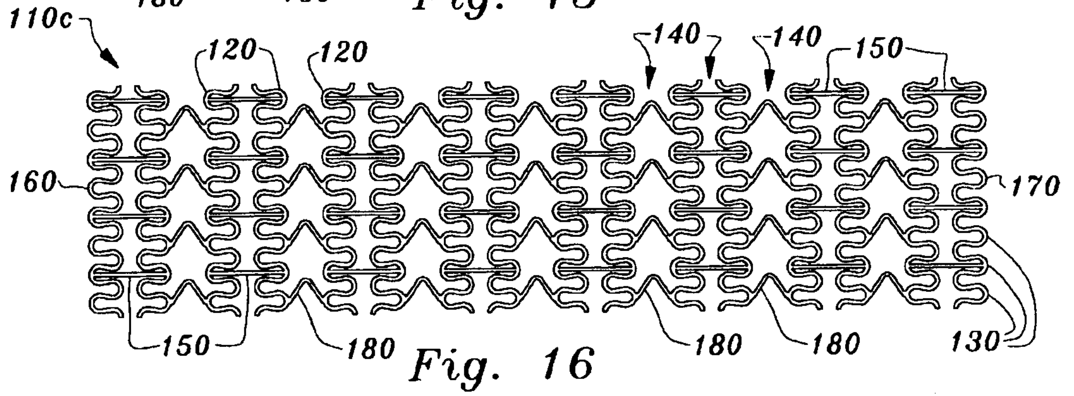


Fig. 16

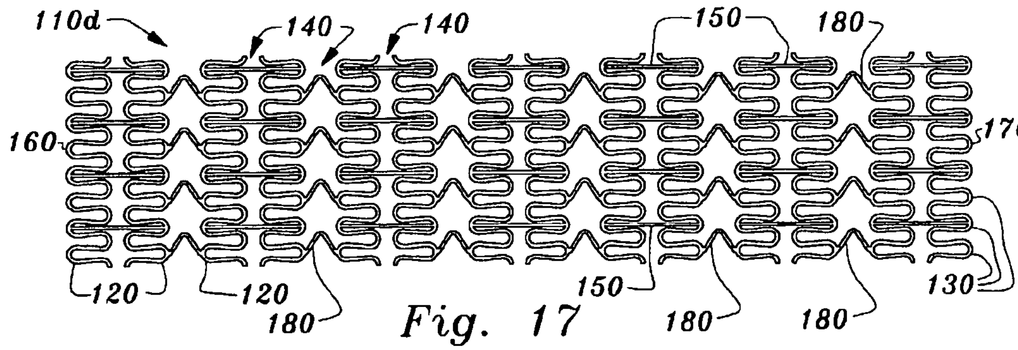


Fig. 17

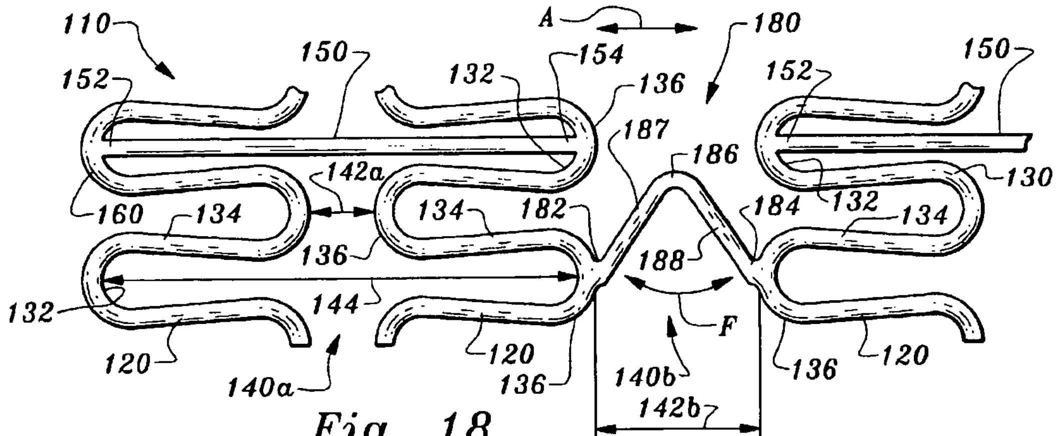


Fig. 18

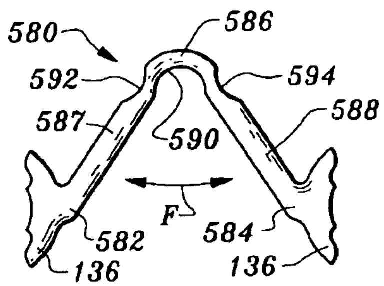


Fig. 19

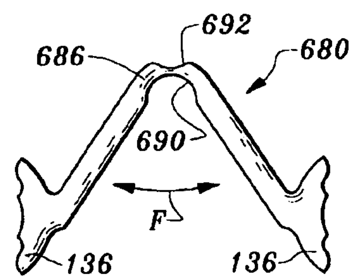


Fig. 20

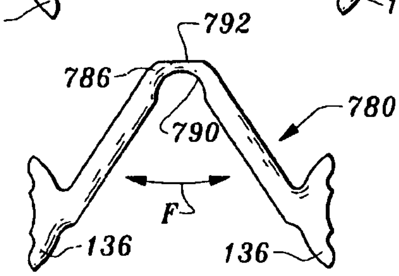
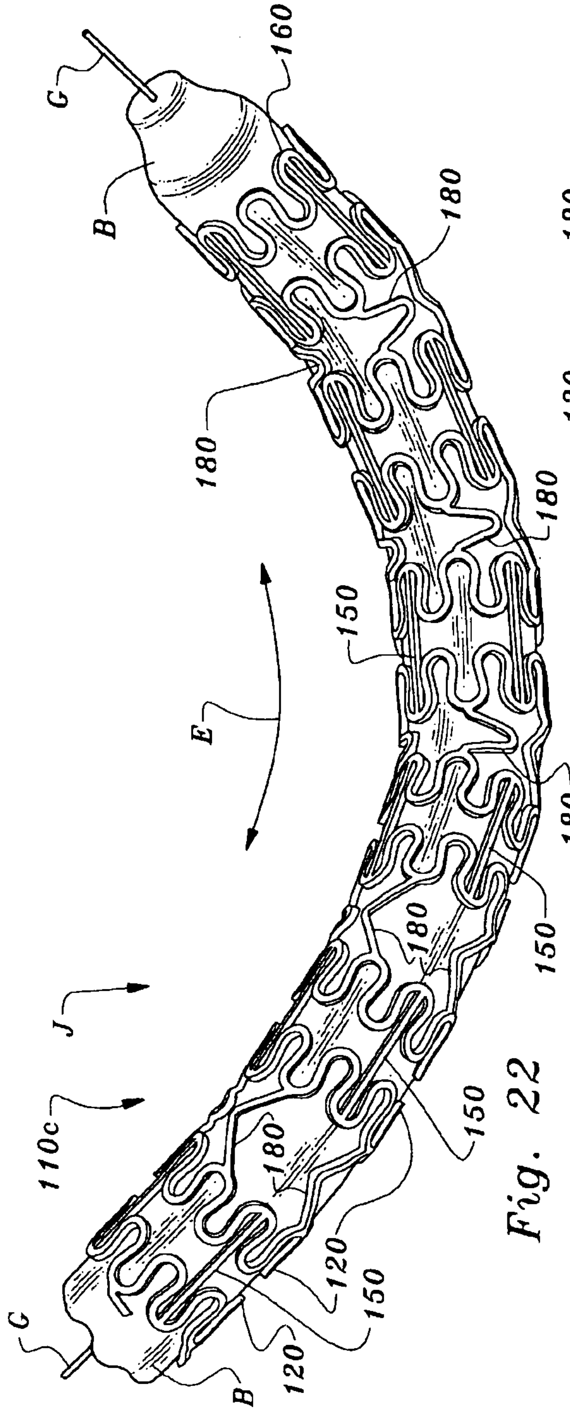


Fig. 21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B
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E
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J
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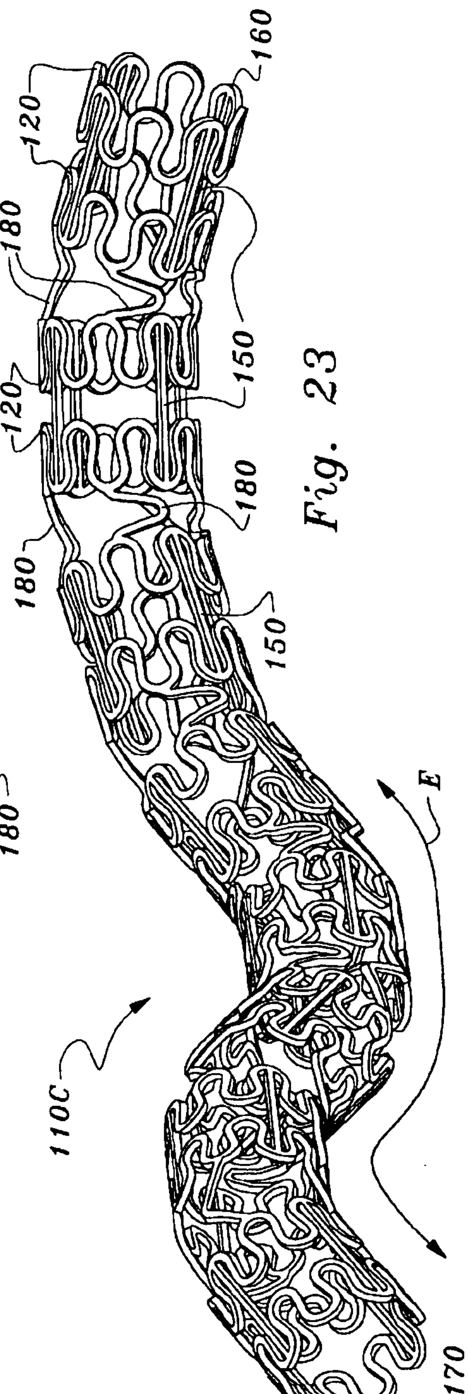
G
B

Fig. 22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110C
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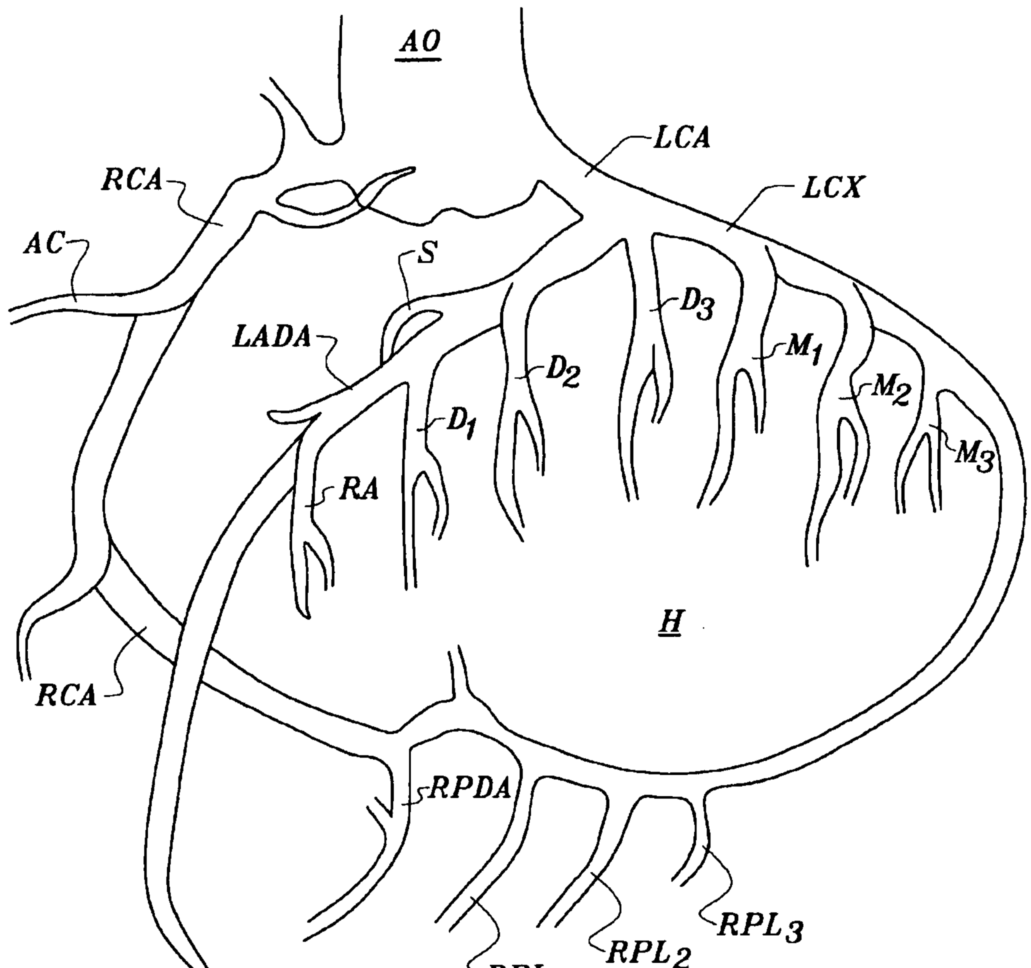
Fig. 23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AC
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LADA
D3
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M1
M2
D1
M3
RA
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RCA
RPDA
RPL3
RPL2
RPL1

Fig. 24

ENHANCED FLEXIBILITY SURGICAL STENT

FIELD OF THE INVENTION

The following invention relates to surgical stents of a generally cylindrical configuration which can be surgically implanted into a body lumen, such as an artery, and radially expanded. More specifically, this invention relates to radially expandable surgical stents which exhibit enhanced flexibility for passage through tortuous arterial pathways and other sharply curved body lumens.

BACKGROUND OF THE INVENTION

Surgical stents have long been known which can be surgically implanted into a body lumen, such as an artery, to reinforce, support, repair or otherwise enhance the performance of the lumen. For instance, in cardiovascular surgery it is often desirable to place a stent in the coronary artery at a location where the artery is damaged or is susceptible to collapse. The stent, once in place, reinforces that portion of the artery allowing normal blood flow to occur through the artery. One form of stent which is particularly desirable for implantation in arteries and other body lumens is a cylindrical stent which can be radially expanded from a first smaller diameter to a second larger diameter. Such radially expandable stents can be inserted into the artery by being located on a catheter and fed internally through the arterial pathways of the patient until the unexpanded stent is located where desired. The catheter is fitted with a balloon or other expansion mechanism which exerts a radial pressure outward on the stent causing the stent to expand radially to a larger diameter. Such expandable stents exhibit sufficient rigidity after being expanded that they will remain expanded after the catheter has been removed.

Radially expandable stents come in a variety of different configurations to provide optimal performance to various different particular circumstances. For instance, the patents to Lau (U.S. Pat. Nos. 5,514,154, 5,421,955, and 5,242,399), Baracci (U.S. Pat. No. 5,531,741), Gaterud (U.S. Pat. No. 5,522,882), Gianturco (U.S. Pat. Nos. 5,507,771 and 5,314,444), Termin (U.S. Pat. No. 5,496,277), Lane (U.S. Pat. No. 5,494,029), Maeda (U.S. Pat. No. 5,507,767), Marin (U.S. Pat. No. 5,443,477), Khosravi (U.S. Pat. No. 5,441,515), Jessen (U.S. Pat. No. 5,425,739), Hickle (U.S. Pat. No. 5,139,480), Schatz (U.S. Pat. No. 5,195,984), Fordenbacher (U.S. Pat. No. 5,549,662) and Wiktor (U.S. Pat. No. 5,133,732), each include some form of radially expandable stent for implantation into a body lumen.

Each of these prior art stents suffer from a variety of drawbacks which make them less than ideal. For instance, many of these expandable stents are not particularly flexible and they have a central axis which remains substantially linear when the stents are not yet expanded. Such lack of flexibility makes the stent difficult to thread along arterial pathways for proper positioning within the body of the patient.

Some arterial pathways are not accessible by prior art surgical stents because of the tortuous nature of these arterial pathways. Without the availability of a stent having sufficient flexibility to navigate these tortuous arterial pathways, such arteries cannot be repaired using known prior art stents.

Another problem which is exhibited by each of these prior art stents is that when they are expanded radially, an axial length of these stents is decreased. Even the patent to Lau (U.S. Pat. No. 5,514,154), although it teaches a stent design which attempts to limit axial contraction, still exhibits some axial contraction, especially at one end thereof.

When a surgeon is positioning a stent within an artery or other body lumen, it is critical that the stent be positioned precisely where the surgeon desires the stent to be placed. A common occurrence with prior art stents is that the stent will be precisely located where desired before radial expansion and then when the stent is expanded, its axial contraction will cause the stent to not be finally located precisely where desired. Such a mis-location problem is compounded by the fact that most stents can only be easily expanded and not easily contracted once expansion has occurred.

Additionally, is is often difficult, even with state of the art medical imaging equipment, to accurately determine the location of a stent during implantation thereof within a body lumen. This difficulty in determining exactly what the position is of the stent compounds the problem of accurately locating the stent where desired. Accordingly, a need exists for a radially expandable stent which exhibits little or no axial contraction when radially expanded and which can be easily located by medical imaging equipment during the stent positioning process.

SUMMARY OF THE INVENTION

This invention provides a radially expandable stent which exhibits little or no contraction along an entire axial length thereof when the stent is expanded radially. The stent includes a series of struts which act as circumferential elements circumscribing the cylindrical contour of the stent. Each strut is aligned with a separate plane perpendicular to a central axis of the cylindrical contour of the stent and parallel to other planes of adjacent struts. The stent can have various different numbers of struts joined together to form the stent. However, at least two end struts are provided including a first end strut and a second end strut which define ends of the cylindrical contour of the stent. Intermediate struts are also typically provided between the two end struts.

Each of these struts exhibits a wave-like contour as they circumscribe the cylindrical contour of the stent. Thus, each strut has a series of bends which have troughs and crests alternating along the length of each strut. Each trough defines a portion of the strut which is most distant from adjacent struts and each crest defines a portion of the strut closest to adjacent struts. An amplitude of each strut, defined by the distance between the bottom of each trough and the top of each crest is modified when the stent is radially expanded so that the amplitude is generally decreased.

The end struts are attached to adjacent intermediate struts by tie bars which act as axial elements connecting the two adjacent struts together. Tie bars can also connect adjacent intermediate struts to each other. Each tie bar attaches to the struts adjacent thereto through a first junction on one extremity of the tie bar and a second junction on an opposite extremity of the tie bar. Both the first junction and the second junction are located within troughs of the struts. Thus, the tie bars span a gap between adjacent struts at a maximum width portion of the gap. Not all of the gaps are necessarily spanned by tie bar axial elements. Rather, separate intermediate circumferential elements can be attached to each other through links which connect to the intermediate elements at locations spaced away from the troughs thereof.

To maximize the flexibility of the stent and allow the stent to navigate highly curved tortuous arterial pathways, axial elements in the form of enhanced flexibility linking elements are provided spanning gaps between some of the struts. The gaps which are spanned by linking elements can be readily bent because the linking elements include a means to expand and contract axially. Each linking element has a left arm and

a right arm connected together by an elbow. The elbow is sufficiently thin that it can bend somewhat, causing the left arm and right arm to flex toward and away from each other, in turn narrowing or expanding portions of the gap adjacent the flexible linking axial element. When the stent is flexed, some linking elements in a gap are contracted and some linking elements in the gap are expanded, causing the gap to have a variable width which is smaller on an inside of the curve of the stent and larger on an outside of the curve of the stent. As the stent moves through the curving arterial pathways, the linking axial elements can expand and contract as necessary to cause the gaps they span to flex and in turn causing the stent itself to flexibly adapt to a contour of the arterial pathway through which the stent is being passed.

Depending on the flexibility needs and strength needs for the stent, different numbers of troughs can be provided with tie bars attaching adjacent struts to each other. Also, a greater overall number of undulations and axial elements can be provided. If enhanced flexibility is desired, a fewer number of axial elements can be provided between adjacent struts or the arms of the linking axial elements can be lengthened. Also, the gaps in which the linking elements are located can be widened. The undulating contour of the struts can either be serpentine with the struts lacking flat surfaces but rather curving entirely along their length, or the struts can be formed from a series of linear sections including linear trough sections and linear crest sections joined together by linear inflection sections.

To enhance the visibility of the stent when viewed by various different medical imaging devices, the struts forming the first end and the second end of the stent can be formed from a radio-opaque material, such as gold, silver or platinum which will allow the first end and second end of the stent to be clearly visible through a medical imaging device during or after implantation of the stent within a body lumen of a patient.

OBJECTS OF THE INVENTION

Accordingly, a primary object of the present invention is to provide a radially expandable stent which does not contract axially when expanded radially.

Another object of the present invention is to provide a stent which exhibits sufficient flexibility to allow a central axis thereof to bend, especially when the stent is being threaded through arterial pathways within a patient.

Another object of the present invention is to provide a surgical stent which exhibits little or no axial contraction at ends thereof when expanded radially.

Another object of the present invention is to provide a surgical stent which has ends thereof formed from a radio-opaque material which can be easily viewed by a medical imaging device.

Another object of the present invention is to provide a surgical stent which is formed from a series of struts which form circumferential elements circumscribing a cylindrical contour of the stent, the individual struts joined together by tie bars which act as axial elements restraining the struts from contracting together when expanded radially.

Another object of the present invention is to provide a surgical stent which has a configuration which lends itself to manufacture from a variety of techniques including machining, photo-etching and other precision low cost techniques.

Another object of the present invention is to provide a surgical stent which has a configuration which exhibits the strength necessary to support a body lumen when implanted therein and radially expanded.

Another object of the present invention is to provide a surgical stent which can be located within a body lumen by a surgeon with a high degree of locational precision.

Another object of the present invention is to provide a surgical stent which is sufficiently flexible that it can be routed through tortuous arterial pathways leading up to a maximum number of potential stent implantation sites, including the diagonal arteries of the left anterior descending artery and the marginal arteries of the left circumflex artery and the right posterior lateral arteries of the heart.

Another object of the present invention is to provide a surgical stent which can be radially expanded to over twice its non-radially expanded diameter, does not substantially contract axially when radially expanded and which has sufficient flexibility to match a flexibility of a guide wire of a stent positioning catheter utilized to position and radially expand the stent.

Another object of the present invention is to provide a surgical stent which features axial elements in the form of flexible links which can expand and contract axially, causing gaps spanned by such flexible links to bend and imparting flexibility to the stent.

Other further objects of the present invention will become apparent from a careful reading of the included description and claims and from a review of the drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a preferred embodiment of the surgical stent of this invention before radial expansion occurs.

FIG. **2** is a perspective view of the stent which is shown in FIG. **1** after radial expansion has occurred.

FIG. **3** is a top plan view of that which is shown in FIG. **1** after cylindrical projection of the stent onto a planar surface to reveal details of the configuration of the stent.

FIG. **4** is a top plan view of the stent which is shown in FIG. **2** after cylindrical projection of the stent onto a planar surface to reveal details of the configuration of the stent after radial expansion.

FIG. **5** is a top plan view of a stent forming a first alternative embodiment of that which is shown in FIG. **3**, before radial expansion.

FIG. **6** is a top plan view of the stent which is shown in FIG. **5** after radial expansion has occurred.

FIG. **7** is a top plan view of a stent forming a second alternative embodiment of that which is shown in FIG. **3**, before radial expansion.

FIG. **8** is a top plan view of the stent which is shown in FIG. **7** after radial expansion has occurred.

FIG. **9** is a top plan view of a stent forming a third alternative embodiment of that which is shown in FIG. **3**, before radial expansion.

FIG. **10** is a top plan view of the stent which is shown in FIG. **9** after radial expansion has occurred.

FIG. **11** is a top plan view of a stent forming an alternative embodiment to that which is shown in FIG. **9** with end struts thereof formed from a material having radio-opaque properties, before radial expansion.

FIG. **12** is a top plan view of the stent which is shown in FIG. **11** after radial expansion thereof.

FIG. **13** is a front elevation view of the stent shown in FIGS. **11** and **12** as it would appear when viewed by a

medical imaging device which more clearly discerns radio-opaque material than non-radio-opaque material, the lumen having been clearly outlined by a radio-opaque dye and portions of the stent formed from non-radio-opaque material shown in broken lines representing that they are only vaguely apparent.

FIG. 14 is a cylindrical projection of an alternative embodiment of the stent shown in FIGS. **5** and **6**, where a greater number of axial linking elements are provided spanning gaps between struts of the stent.

FIG. **15** is a cylindrical projection of another alternative embodiment of that which is shown in FIGS. **5** and **6** where five links are provided spanning each gap and five tie bars are provided spanning each gap and where a greater number of bends are provided for each strut.

FIG. **16** is a cylindrical projection of another alternative embodiment of that which is shown in FIGS. **5** and **6** where four tie bars are provided spanning each gap and four links are provided spanning each gap and where a greater number of bends than that shown in FIGS. **5** and **6** are provided.

FIG. 17 is a cylindrical projection of an alternative to that which is shown in FIG. **16** where the struts exhibit a greater amplitude for a greater amount of radial expansion of the stent.

FIG. **18** is a cylindrical projection of a portion of that which is shown in FIG. **17** revealing details of the flexible axial linking elements of this invention.

FIGS. **19–21** are cylindrical projections of a portion of that which is shown in FIG. **18** revealing three alternative embodiments for an elbow of the flexible axial linking element of the stent.

FIG. **22** is a perspective view of one of the stents of this invention in position upon a catheter with the catheter flexed as it would be when passing through a sharp curve in a body lumen prior to radial expansion of the stent.

FIG. **23** is a perspective view of one of the stents of this invention revealing how the stent can be flexed sufficiently to follow tortuous arterial pathways.

FIG. **24** is a schematic representation of arterial pathways of a heart which identifies some potential sites for implantation of the surgical stents of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, wherein like reference numerals represent like parts throughout the various drawing figures, reference numeral **10** is directed to a radially expandable axially non-contracting surgical stent (FIGS. **1** and **2**). The stent **10** generally exhibits a cylindrical contour defined by a series of circumferential elements, referred to as struts **20**, tied together by multiple axial elements, many of which are referred to as tie bars **50**. The struts **20** are generally wave-like in form such that an amplitude **22** (FIG. **4**) of the struts **20** can be decreased and a diameter of the struts **20** increased, as the diameter of the stent **10** is radially expanded.

In essence, and with particular reference to FIGS. **1** and **2**, the stent **10** includes the following basic features. A series of circumferential elements such as struts ***20a***, ***20b***, ***20c***, ***20d***, ***20e***, ***20f*** are each oriented in a manner circumscribing the cylindrical contour of the stent **10**. Each strut **20** includes a series of bends **30** (FIGS. **3** and **4**) providing the strut **20** with its wave-like form. Each strut **20** is spaced from adjacent struts **20** by a gap **40** there between. A series of tie bars **50** extend between adjacent struts **20**, and across the gap **40**, connecting the adjacent struts **20** to each other. The tie bars **50** act as axial elements maintaining the axial position of the struts **20** during radial expansion of the stent **10** along arrow R (FIG. **2**). The tie bars **50** are sufficiently flexible and spaced sufficiently apart from other tie bars **50** that the entire stent **10** can flex somewhat causing the central axis **2** to bend as the stent **10** is moved through arterial pathways or other body lumens before radial expansion of the stent **10**.

More specifically, and with particular reference to FIGS. **1** through **4**, details of the surgical stent **10** are specifically provided. Each strut **20** preferably is a thin elongate strand of material such as metal which is confined to lie substantially within a cylindrical contour forming the stent **10**. Each strut **20** exhibits a wave-like contour having a constant amplitude **22** (FIG. **4**) and wavelength **24** (FIG. **4**) as it circumscribes the cylindrical contour of the stent **10**. Each strut **20** thus has bends **30** therein which provide a series of alternating troughs **32** and crests **36**. Between each adjacent trough **32** and crest **36** an inflection point **34** is provided which defines a transition between the trough **32** and the crest **36**.

Whether a portion of a bend **30** is a trough **32** or a crest **36** is largely a matter of perspective. For consistency and with particular reference to FIG. **4**, the trough **32** shall be identified as that portion of each bend **30** which is most distant from the adjacent strut **20** that the bend is facing, and the crest **36** is that portion of each bend **30** which is closest to the adjacent strut **20** that the bend **30** is facing. Each trough **32** and crest **36** is not a particular point on each bend **30**, but rather is a region extending from one inflection point **34** to the next adjacent inflection point **34** along each strut **20**. Whether a portion of a bend **30** is a trough **32** or a crest **36** also depends on the side of each bend **30** that is being analyzed. For example, a bend **30** spaced from a first end **60** and a second end **70** of the stent **10** can have a crest **36** on one side of the bend **30** closest to the first end **60** and a trough **32** on the other side of the same bend **30** closest to the second end **70**.

Each inflection point **34** is the point at which the bend **30** transitions from curving in one direction (i.e. in a clockwise direction) to curving in an opposite direction (i.e. a counterclockwise direction). Each inflection point **34** is preferably a single point which occurs at the beginning and a middle of each wavelength **24** of each strut **20**. However, the inflection point **34** can alternatively be a linear region between each crest **36** and each trough **32**, rather than merely a point. Preferably, each strut **20** is aligned with adjacent struts **20** so that the troughs **32** of adjacent struts **20** are axially aligned with each other and the crests **36** of each strut **20** are axially aligned with each other.

A gap **40** is located between each pair of adjacent struts **20**. Thus, end struts **20** such as the strut ***20a*** adjacent the first end **60** and the strut ***20f*** adjacent the second end **70** have only one gap **40** adjacent thereto and intermediate struts ***20b***, ***20c***, ***20d***, ***20e*** have gaps **40** on either side. Preferably, each gap **40** defines a space between adjacent struts **20** which is not crossed by either strut **20** which is adjacent each gap **40**. Rather, the tie bars **50**, described in detail below, are provided to span the gaps **40**.

Each gap **40** has a width which varies depending on whether the gap **40** location is adjacent troughs **32** of adjacent struts **20** or crests **36** of adjacent struts **20**. At locations on the gap **40** adjacent to the crests **36** of adjacent struts **20**, a minimum width **42** in the gap **40** is defined (FIG. **4**). At locations along the gap **40** adjacent the troughs **32** of

adjacent struts **20**, a maximum width **44** in the gap **40** is defined (FIG. **4**). Each gap **40** thus exhibits an alternating pattern of minimums **42** and maximums **44** as the gap **40** circumscribes the cylindrical contour of the stent **10**.

Each maximum **44** also defines a lateral slot **46** (FIG. **4**) where the gap **40** extends a significant distance away from a central plane of the gap **40** and toward adjacent struts **20**. The slot **46** has a contour which is defined by the configuration of the bends **30** of adjacent struts **20** and the radial expansion status of the stent **10** (i.e. before radial expansion along arrow R of FIG. 2 or after radial expansion). Preferably, before radial expansion along arrow R (FIG. 2), each slot **46** (FIG. 4) has a bulbous contour (FIG. 3) which mirrors a bulbous contour of the bends **30** such that the slot **46** first narrows and then expands as the slot **46** extends away from a center plane of the gap **40** and down into one of the troughs **32** in one of the bends **30** of an adjacent strut **20**. After the stent **10** has been radially expanded (FIG. 4), the slots **46** lose this bulbous character and rather have a contour which tapers in width as the slots **46** extend away from a central plane of the gap **40**.

By configuring the struts **20** to have this characteristic of bends **30** with a bulbous contour, providing the slots **46** with a narrowing and then expanding width, the struts **20** are allowed to expand further radially, along arrow R. This allows the stent **10** to extend to a greater length circumferentially, along arrow C (FIGS. 2 and 4), maximizing radial expandability thereof. This bulbous contour of the slots **46** also tends to allow the amplitude **22** (FIG. 4) of the struts **20** to remain unchanged during initial expansion of the stent **10** radially. Only after significant radial expansion and circumferential elongation does the amplitude **22** of the struts **20** begin to significantly decrease.

At least one tie bar **50** is oriented within each gap **40**. The tie bar **50** is preferably a thin elongate structure having a first extremity spaced from a second extremity. The first extremity attaches to a first adjacent strut **20** at a first junction **52** and the second extremity attaches to a second adjacent strut **20** at a second junction **54**. The first junction **52** and second junction **54** are both preferably located within troughs **32** of the struts **20** which are adjacent the gap **40** that is spanned by the tie bar **50**.

To prevent axial contraction along arrow A (FIG. 2) during radial expansion of the stent **10**, it is important that at least the extremities of the tie bar **50** which connect to end struts **20*a*, 20*f*** adjacent the first end **60** and the second end **70** attach to troughs **32** of the end struts **20*a*, 20*f***. The second extremities of the tie bar **50** which connect to intermediate struts **20** spaced from the first end **60** and the second end **70** can either be attached within troughs **32** or crests **36**.

With at least one tie bar **50** in place across each gap **40** and with the junctions **52, 54** located in troughs **32**, the length of the slots **46** in the gap **40** are maintained. Thus, when the stent **10** is radially expanded along arrow R to the point where the amplitude **22** of the struts **20** adjacent each gap **40** begins to decrease, the struts **20** adjacent each gap **40** are not contracted together. Rather, the minimums **42** in the gaps **40** are enlarged and the struts **20**, and particularly the end struts **20*a*, 20*f*** maintain their position. Hence, no axial contraction along arrow A occurs.

Of primary importance in configuring the stent **10** is that gaps **40** adjacent the first end **60** and second end **70** be spanned by tie bars **50** which attach within troughs **32** in the struts **20*a*, 20*f***defining the first end **60** and the second end **70**. Additionally, the other tie bars **50** between intermediate struts **20*b*, 20*c*, 20*d*, 20*e*** can either be located in troughs **32** or at crests **36**. However, the tie bars **50** between adjacent intermediate struts **20*b*, 20*c*, 20*d*, 20*e*** should attach to at least an equal number of troughs **32** and crests **36** if not a greater number of roughs **32**, as shown in FIGS. 1–4 where tie bars **50** only attach to troughs **32**.

It has been determined from experience that the thin cross sections of the tie bars **50** cause the tie bars **50** to bend somewhat in many cases. Thus, it is beneficial to have a greater number of gaps **40** spanned by tie bars **50** which connect to adjacent struts **20** at troughs **32** thereof than tie bars **50** which attach to crests **36** thereof, to compensate for the possibility of flexing of the tie bars **50**.

Preferably, each gap **40** is provided with tie bars **50** which extend from troughs **34** of each adjacent strut **20**. While in theory such a configuration could actually cause the stent **10** to expand axially along arrow A when expanded radially along arrow R, the tie bars **50** bend somewhat when located within a body lumen and hence are slightly shortened, causing the stent **10** to in reality remain substantially the same axial length as before expansion, with only the slight possibility of a minimal amount of either contraction or expansion. For reference, it is noted that even so called non-contracting stents, such as the expandable stent taught by Lau (U.S. Pat. No. 5,514,154), can contract as much as one half of the amplitude of circumferential elements forming such prior art stents. This contraction of prior art stents such as that taught by Lau particularly occurs at ends of the stents where axial elements join circumferential elements at crests in the circumferential elements.

The material forming the struts **20** and other elements of the stent **10** are preferably made of a stainless steel having a sufficiently minimal cross section that the struts **20** can be easily loaded with radial force, such as along arrow R (FIG. 2), to a point exceeding the elastic limit of the material forming the struts **20**. When such a radial force is applied, the material forming the struts **20** is plastically deformed, causing the struts **20** to expand radially, elongate circumferentially and contract in amplitude. Such deformation of the material forming the struts **20** could in theory occur until the struts **20** were deformed into the shape of a circle before additional deformation would eventually cause failure of the struts **20** in tension.

In practice however, the stent **10** is provided with overall structural strength by not expanding the stent **10** to its maximum possible amount, but rather to a point where the struts **20** still exhibit a wave-like appearance with the amplitude only slightly decreased and the wave length of the struts **20** magnified by a similar amount to the amount of magnification in the circumferential length of each strut **20**. Although the struts **20** have undergone plastic deformation, the ultimate strength of the material forming the struts **20** has not been exceeded. Thus, the material still exhibits similar characteristics as far as strength is concerned and can provide the desired function of supporting a body lumen in its expanded configuration.

It is noted that stainless steel has a yield strength of between 40,000 and 75,000 pounds per square inch and an ultimate strength of between 90,000 and 125,000 pounds per square inch. Thus, it is relatively straight forward to provide sufficient radial force on the stent **10** to cause the material forming the struts **20** to have its yield strength exceeded but to not have its ultimate strength exceeded. This is especially true in that the struts **20** are actually "bending" and not "stretching" during the radial expansion process. Techniques for expanding stents such as the stent **10** are well known in the art. One such technique involves placing an expandable

balloon within the stent which can be filled with air or other fluid, causing the balloon to elastically expand and exert a radial force on the stent. Specific details of such expansion techniques are articulated in the patents cited in the background of the invention and are incorporated herein by reference.

As an alternative to the surgical stent **10** of the preferred embodiment, a surgical stent **110** (FIGS. **5** and **6**) is provided featuring links **180** spanning certain of the portions of the stent **110**. The stent **110** is similar in configuration to the stent **10** of the preferred embodiment except as specifically identified below. Thus, the stent **110** includes struts **120** which provide circumferential elements for the stent **110** with bends **130** similar to the bends **30** in the struts **20** of the preferred embodiment and gaps **140** between adjacent struts **120**. Each bend **130** includes a series of alternating troughs **132** and crests **136**. Tie bars **150** similar to the tie bars **50** of the preferred embodiment are interposed across some of the gaps **140**, while other gaps **140** are provided with the links **180**. Preferably, the gaps **140** adjacent the first end **160** and the second end **170** are provided with tie bars **150** therein. In addition, these tie bars **150** are preferably oriented between troughs **132** of adjacent struts **120**. Other gaps **140** spaced away from the first end **160** and second end **170** can either include tie bars **150** or links **180**.

Each link **180** is a thin elongate structure having a left end **182** (FIG. **6**), a right end **184** and an elbow **186** located medially between the left end **182** and the right end **184**. Thus, the link **180** is provided with a left arm **187** extending from the left end **182** to the elbow **186** and a right arm **188** extending from the right end **184** to the elbow **186**. Preferably, the elbow **186** causes the left arm **187** to be perpendicular to the right arm **188**. The elbow **186** provides a particular location where the left arm **187** and right arm **188** of each link **180** can flex toward or away from each other about arrow F (FIG. **6**) in a manner facilitating flexibility for the entire stent **110** when being threaded through arterial pathways.

The links **180** are preferably oriented at minimums **142** in the gap **140** in which the links **180** are located. Preferably, gaps **140** having the links **180** located therein alternate with gaps **140** having the tie bars **150** located therein and do not include gaps **140** adjacent the first end **160** and second end **170**. When the stent **110** is expanded radially, and an amplitude of the bends **130** and the struts **120** is decreased, the links **180** will hold crests **136** of adjacent struts **120** together across the gaps **140**. This will tend to have a contraction effect on the stent **110**. However, the tie bars **150** being interposed between troughs **132** and adjacent struts **120** will tend to have an expanding effect on the stent **110**. The net result of the tie bars **150** providing an axially expanding effect and the links **180** providing an axially contracting effect is that the stent **110** is provided with no or minimal net contraction when the stent **110** is expanded radially.

Preferably, the gaps **140** having tie bars **150** therein are provided with three tie bars **150** and the struts 120 are provided with six troughs **132** and six crests **136** such that only half of the possible tie bar **150** locations are utilized. Preferably, the gaps **140** fitted with links **180** include only two links **180** therein. Thus, four minimums **142** are left vacant. The locations of the links **180** are preferably circumferentially offset with the locations of the tie bars **150** to further enhance flexibility of the stent **110**. Other stent designs similar to the surgical stent **110** featuring links **180** are shown in detail in FIGS. **14–23** with further details of such stents which enhance their flexibility further explained.

With particular reference to FIGS. **7** and **8**, details of a second alternative embodiment of the stent **10** featuring links and struts formed of individual linear segments is provided. Such a stent **210** still exhibits a cylindrical contour defined by a plurality of struts **220**. Only those details of this stent **210** which differ from details of the stent **10** of the preferred embodiment will be provided in detail below. Each of the struts **220** has a wave-like appearance with a series of bends **230** located therein. However, each bend **230** is provided with a flat trough **234** (FIG. **8**) parallel to and axially spaced from a plurality of flat crests **236**. Each flat trough **234** and flat crest **236** is preferably oriented within a plane perpendicular to the central axis (see the central axis **2** of FIG. **2**) of the stent **210**.

Each flat trough **234** is connected to adjacent flat crests **236** by inflection legs **235**. Each inflection leg **235** is preferably linear and is non-parallel with either the flat trough **234** or the flat crest **236**. Corners **237** are provided at transitions between ends of the inflection legs **235** and adjacent flat troughs **234** and flat crests **236**. The stent **210** expands radially in a similar manner to the stent **10** of the preferred embodiment except that the struts **220** are modified from a somewhat rectangular configuration for the bends **230** to a trapezoidal configuration for the bends **230**. The amplitude **222** of the struts **220** is decreased when radial expansion occurs and the wave length **224** of the struts **220** is increased when radial expansion occurs in a manner similar to that exhibited by the stent **10** of the preferred embodiment.

Gaps **240** are oriented between adjacent struts **220** in the stent **210**. Tie bars **250** are provided between flat troughs **234** in adjacent struts **220** and spanning the gaps **240**. Such tie bars **250** are preferably located at the gaps **240** adjacent a first end **260** and a second end **270** and are optional at other gaps **240** in the stent **210**.

As an alternative to the tie bars **250**, the gaps **240** can be spanned by arched links **280** (FIG. **8**). Preferably, each arched link **280** has a left end **282** spaced from a right end **284** and is bowed between the left end **282** and the right end **284**. Preferably, the arched links **280** are interposed between adjacent flat crests **236** of struts **220** adjacent the gap **240** spanned by the arched link **280**. The arched link **280** provides a similar function to that provided by the link **180** of the first alternative embodiment in that it joins adjacent gaps **240** to provide localized contraction to offset localized expansion caused by the tie bars **250** and allow the stent **210** as a whole to exhibit little if any contraction or expansion in the axial direction when radially expanded.

As an alternative to the strut **220**, the arched links **280** can be replaced with links **180**. Preferably in this embodiment, each flat trough **234** facing a gap **240** includes a tie bar **250** therein and each flat crest **236** adjacent a gap **240** including an arched link **280** attached thereto. Thus, no vacancies are provided in any of the flat troughs **234** or flat crests **236**. In such a configuration, the stent **210** is provided with minimal flexibility for applications where radial strength is of primary importance and flexibility is of secondary importance. As an alternative, vacancies can be provided in the troughs **234** and the crests **236** in a manner similar to the preferred embodiment or the first alternative embodiment.

With particular reference to FIGS. **9** and **10**, details of a third alternative embodiment is provided of the surgical stent **10** of the preferred embodiment. This third alternative embodiment is for a stent **310** featuring multi-element junctions **380** therein. Details of the stent **310** are similar to those of the stent **210** except where particularly provided

below. The stent **310** thus includes a series of struts **320** which circumscribe a cylindrical contour of the stent **310** and which exhibit a wave-like contour having bends **330**. Gaps **340** are provided between adjacent struts **320**. Alternating gaps **340**, and particularly the gaps **340** adjacent the first end **360** and the second end **370** are fitted with tie bars **350** therein. Other gaps **340** can be fitted with either tie bars **350** or have a width thereof reduced to zero and have crests of struts **320** adjacent the gap **340** attached together at multi-element junctions **380**.

In essence, the multi-element junction **380** replaces the arched link **280** of the second alternative embodiment and causes the gap **340** having multi-element junctions **380** therein to be reduced to a width of zero. The stent **310** is expandable in a manner similar to the stent **210**. However, it is noted that because the tie bars **250** are aligned with the multi-element junctions **280**, each of the individual tie bars **250** forms a continuous axial element extending from the first end **360** to the second end **370**. Thus, an axial length of the stent **310** is maintained without contraction to a high degree of precision. The only possibility of axial contraction comes from any possible tie bar **350** bending, rather than the arrangement of the elements forming the stent **310**. The tie bars **350** also provide a limited amount of flex for the stent **310**. However, the stent **310** does not exhibit as much flexibility as the stents **10**, **110**, **210** of the other embodiments and is particularly suited for applications where flexibility is truly secondary and lack of axial contraction and radial strength are of primary importance.

With particular reference to FIGS. 11, 12 and 13, details of a fourth alternative embodiment are provided. The stent **410** is only described to the extent that details thereof are distinct from details of the stent **310** of the third alternative embodiment. The stent **410** thus includes a series of struts **420** circumscribing the cylindrical contour of the stent **410**. A first end strut **426** is located adjacent the first end **460** and a second end strut **428** is located adjacent the second end **470**. These end struts **426**, **428** are formed from a unique material from the material forming the middle struts **420** and other elements of the stent **410**. This use of a different material than the material forming other elements of the stent **410** for the end struts **426**, **428** could be similarly incorporated into the other stents **10**, **110**, **210**, **310** of the other embodiments in a similar manner. The material forming the end struts **426**, **428** is preferably a material exhibiting opacity when viewed by a medical imaging device to a greater extent than the material forming other portions of the stent **410**. For instance, when stainless steel is utilized to form other portions of the stent **410**, the end struts **426**, **428** can be formed from a material such as gold, platinum, silver or some alloy or amalgam thereof, or other similar sufficiently dense material to provide a clear image when viewed by a medical imaging device.

The end struts **426**, **428** are not namely plated with radio-opaque material. Rather the end struts **426**, **428** are constructed out of the radio-opaque material. This is important because plating of stents, such as the stent **410**, cause a thickness of elements forming the stents to be increased by a few thousandths of an inch. Such a plated stent then becomes difficult to maneuver through arterial pathways and other degradation in performance. Also, when end struts are thickened by plating, the radio-opaque material has a relatively broad profile that can be excessively bright when viewed with a fluoroscope or other medical imaging device, causing the stent's radio-opaque ends to appear blurry and not precisely defined. By forming the end struts **426**, **428** entirely of radio-opaque material, the plating drawbacks are avoided.

As shown in FIG. **13**, when the end struts **426**, **428** are formed from a "radio-opaque" material, as described above, the ends **460**, **470** of the stent **410** are clearly discernible when utilizing the medical imaging device. Additionally, the lumen L in which the stent **410** is located can be highlighted in a medical imaging device by coating the lumen L with a radio-opaque dye as is known in the art. A medical imaging device, such as an X-ray, can then be utilized to precisely determine the exact location of the stent **410** within the lumen L prior to or after expansion of the stent **410**. Other portions of the stent **410** are either invisible when viewed with a medical imaging device or only vaguely discernible, as exhibited by FIG. **13** with broken lines. Preferably, the radio-opaque material forming the end struts **426**, **428** is not merely a plating applied to the end struts **426**, **428** but rather the end struts **426**, **428** are formed entirely from the material selected.

In use and operation, and with particular reference to FIGS. **1**, **2** and **13**, details of the operation of the stents **10**, **110**, **210**, **310**, **410** are described. Initially, the stent **10** or alternative embodiment stents **110**, **210**, **310**, **410** is provided in its non-radially expanded configuration as shown in FIG. **1**. The stent is located at the desired position, utilizing prior art techniques such as catheterization, until the stent **10** is positioned where desired. The stent **10** is then expanded radially, along arrow R (FIG. **2**), causing the wavelength **24** to increase, the amplitude **22** to decrease and the circumferential length (along arrow C of FIG. **2**) to increase until the stent **10** is provided with the expanded diameter desired for the particular medical application. Because the stent **10** is configured as disclosed hereinabove and shown in the drawings, the first end **60** and second end **70** remain precisely positioned with respect to each other and with respect to the body lumen during the entire expansion process. Hence, little or no expansion or contraction of the stent **10** occurs.

When the stent **410** of the fourth alternative embodiment is utilized, the stent **410** is positioned as discussed above with respect to the preferred embodiment. However, before expansion of the stent **410** a radio-opaque dye is injected into the lumen involved and a medical imaging device, such as an X-ray machine, is utilized to verify that the stent **410** is positioned precisely where desired. If the position of the stent **410** is not precisely where desired, additional manipulation of the stent **410** can be done before expansion of the stent **410** has occurred. Once the medical professional is confident that the stent **410** is positioned where desired, the stent **410** is expanded as discussed above with respect to the preferred embodiment. Medical imaging devices can then be used immediately there after and on a follow-up basis to verify that the stent **410** is still in the desired position for maximum medical efficacy.

With particular reference to FIGS. **14**–**23**, details of variations to the stent **110** (FIGS. **5** and **6**) featuring links **180** as axial elements spanning gaps **140** of the stent **110** are described in detail. These different variations exemplify the range of configurations which the stent **110** can display for enhanced flexibility while maintaining the basic configuration of struts **120** spaced by gaps **140** with either tie bars **150** or links **180** spanning the gaps **140**. A first enhanced flexibility stent **110***a* is shown in FIG. **14** which is similar to the stent **110** of FIGS. **5** and **6** except that three links **180** span each gap **140** where links **180** are located rather than only two links **180** as shown in the stent **110** of FIGS. **5** and **6**. This enhanced flexibility stent **110***a* has a more radially symmetrical configuration than the stent **110** of FIGS. **5** and **6** so uniform flexibility is provided for the stent **110***a*.

The enhanced flexibility stent **110***b* of FIG. **15** similarly features a series of struts **120** spaced from each other by gaps **140** with either tie bars **150** or links **180** spanning each gap **140**. The enhanced flexibility stent **110***b* (FIG. **15**) differs from other enhanced flexibility stents **110**, **110***a* described above in that each strut **120** includes ten bends **130** as the strut **120** circumscribes the stent **110***b*, rather than merely six bends **130** as shown in FIGS. **5**, **6** and **14** for stents **110**, **110***a*. Additionally, five tie bars **150** and five links **180** are provided within each gap **140**. Additionally, extra struts **120**, a total of sixteen, extend between the first end **160** and the second end **170** rather than fourteen struts **120** between the first end **160** and the second end **170** as shown in the enhanced flexibility stent **110***a* of FIG. **14**.

The enhanced flexibility stent **110***c* is shown in FIG. **16**. The stent **110***c* is similar to the enhanced flexibility stent **110***b* of FIG. **15** except that eight bends **130** are provided on each strut **120** and four tie bars **150** and four links **180** span each gap **140**.

The enhanced flexibility stent **110***d* shown in FIG. **17** is similar to the enhanced flexibility stent **110***c* of FIG. **16** except that the struts **120** have a slightly different contour in the enhanced flexibility stent **110***d* than in the enhanced flexibility **110***c* of FIG. **16**. Specifically, the struts **120** of the enhanced flexibility stent **110***d* have a larger amplitude (analogous to the amplitude **22** shown in FIG. **4**) than an amplitude of the struts **120** of the other enhanced flexibility stents **110**, **110***a*, **110***b*, **110***c* shown in FIGS. **5**, **6** and **14–16**. With a greater amplitude, the struts **120** can be radially expanded a greater amount, such that the enhanced flexibility stent **110***d* can experience a greater amount of radial expansion during implantation within a body lumen, as discussed above.

With particular reference to FIG. **18**, the specific features of individual components of the stent **110**, which are also similarly shared by the stents **110***a*, **110***b*, **110***c*, **110***d* are shown in detail. Each strut **120** includes a series of bends **130** which alternative between troughs **132** and crests **136**. Gaps **140** are provided between each strut **120**. Each gap **140** is not the same. Rather, preferably the gaps **140** are divided into narrow gaps **140***a* and wide gaps **140***b* . The narrow gaps **140***a* are provided between struts **120** where a tie bar **150** is to be located. The wide gaps **140***b* are provided where the links **180** are provided. By making the gaps **140***b* wider than the gaps **140***a* and placing the links **180** within the wide gaps **140***b*, a greater amount of flexibility is allowed by the links **180** within the wide gaps **140***b* before struts **120** on opposite sides of the gaps **140***b* interfere with each other. Each gap **140***a*, **140***b* includes minimum widths **142***a*, **142***b* defining portions of the gaps **140***a*, **140***b* where a least spacing between adjacent struts **120** is provided. Each gap **140***a* , **140***b* also includes a maximum **144** where a maximum width is provided between adjacent struts **120**.

Each tie bar **150** extends linearly and axially between a first junction **152** and a second junction **154**. As discussed above, preferably both the first junction **152** and the second junction **154** are located within troughs **132** in each bend **130** such that the tie bars **150** span maximum width portions **144** of the narrow gaps **140***a*.

Each link **180** acts as an axial element which adds flexibility to the stent **110**. In addition to the basic elements of the link **180** identified above with respect to FIGS. **5** and **6**, the link **180** preferably features an elbow **186** which is configured with a means to flex, along arrow F, enhancing overall flexibility of the stent **110**. Particularly, FIGS. **19–21** show three flex enhancement links **580**, **680**, **780** which reveal three alternative embodiments for enhancing the flexibility of the elbows **186** of the links **180** of the stent **110**.

The first flex enhancement link **580** features a left end **582** adjacent one crest **136** and a right end **584** adjacent another crest **136**. An elbow **586** is located between a left arm **587** extending from the left end **582** and a right arm **588** extending from the right end **584**. Each arm **587**, **588** extends linearly (when viewed in a two dimensional projection) from one of the ends **582**, **584** to the elbow **586**. In actuality, the arms **587**, **588** curve slightly to follow the cylindrical contour of the stent **110** (see FIGS. **22** and **23**).

The elbow **586** includes a bight **590** on an inside portion of the elbow **586** and a left depression **592** on an outside portion of the elbow **586** adjacent the left arm **587** and a right depression **594** on a portion of the elbow **586** adjacent the right arm **588**. The elbow **586** has a width between the bight **590** and the left depression **592** and right depression **594** which is less than a thickness of the left arm **587** and the right arm **588**.

This lessening in thickness can either be caused by forming the elbow **586** with this desired thinness initially or can be provided during a later step in the formation of the stent **110**. For instance, when electropolishing or other polishing techniques are utilized, the elbow **586** being a point where a sharp bend occurs, provides a zone of concentrated charge where a greater amount of electropolishing occurs and which naturally results in the elbow **586** polishing down to a contour having a lesser thickness.

A second flex enhancement link **680** (FIG. **20**) is similar to the first flex enhancement link **580** except that the elbow **686** of the second flex enhancement link **680** has an outside depression **592** opposite the bight **590** so that only a single narrow location in the elbow **686** is provided. The third flex enhancement link **780** (FIG. **21**) is similar to the second flex enhancement link **680** except that the elbow **786** has a flat outside truncation **792** opposite the bight **590** to provide the elbow **786** with the desired thinness compared to the arms such as the arms **587**, **588** of the first flex enhancement link **580**, for facilitating flexing of the links **580**, **680**, **780** at the elbows **586**, **686**, **786**.

If desired, the arms **187**, **188** can be enlarged rather than reducing a thickness of the link **180** adjacent the elbow **186**, so long as the elbow **186** has a lesser thickness than the arms **187**, **188** of the link **180**. Flexing of the link **180**, along arrow F, is thus concentrated at the elbow **186**. Flexing, along arrow F, can occur both in an elongating manner and in a shortening manner for the link **180**, depending on whether tension or compression forces are applied to the link **180**. In fact, when the stent **110** is bending (see FIGS. **22** and **23**) each gap **140** having links **180** therein will have some links **180** on an inside curve of the stent **110** which are being compressed and other links **180** on the same gap **140** which are on the outside of the curve of the stent **110** and hence are being elongated.

Preferably, the elbows **186** of the links **180** do not elastically allow the arms **187**, **188** to bend toward and away from each other, but rather flex in a plastic manner such that if unloaded after being flexed, the arms **187**, **188** will retain the orientation which they exhibited when loaded with a compression or a tension load. However, when forces are again applied in an opposite direction, because the elbow **186** is a region of least thickness on the link **180**, the elbow **186** will readily bend in an opposite direction allowing the link **180** to return to its original shape and to flex to other shapes as required to allow the stent **110** to flex. Such plastic flexing allows the stent **110** to hold a curve within a body

lumen and not tend to try to straighten the body lumen in which the stent **110** is located.

To ensure that the plastic deformation of the links **180** and other portions of the stent **110** do not result in fracture of the stent **110**, it is desireable that the stent **110** be heat treated to minimize brittleness for the stent **110**. For instance, after manufacture of the stent **110**, the stent **110** can be heated and then quenched as desired to produce a grain size consistent with the amount of flexibility and hardness which would give the stent the strength characteristics desired and yet avoid excessive brittleness.

With particular reference to FIGS. **22** and **23**, details of the flexing characteristics of the enhanced flexibility stent **110***c* are shown in detail. In FIG. **22**, the stent **110***c* is shown overlying a catheter J which includes a guide wire G and a balloon B surrounding the guide wire G. The catheter J and stent **110**care both flexed along a curve designated by arrow E. Each of the tie bars **150** and the struts **120** adjacent the tie bars **150** remains substantially axially aligned linearly without any flexing. However, gaps **140** (FIG. **17**) which include the links **180** are altered so that portions of the gaps **140** are compressed and portions of the gaps **140** are expanded. Links **180** within the gaps **140** are either compressed to a lesser overall length or expanded to a greater overall length depending on whether the links **180** are on an inner side of the curve E or on an outer side of the curve E.

The guide wire G is utilized to lead the catheter J with the stent **110** thereon, down a desired arterial pathway for implantation. The balloon B can be blown up to radially expand the stent **110***c* to a desired final diameter. Because the stent **110***c* exhibits enhanced flexibility when compared to prior art stents, the stent **110***c* does not restrict an amount of flexibility the catheter J can exhibit. Rather, the stent **110***c* can freely flex along with the catheter J and follow the catheter J to whatever arterial pathway is desired for implantation of the stent **110***c*. The stent **110***c* is not merely restricted to curvature about a single axis. Rather, the stent **110***c* can flex helically or spirally as depicted in FIG. **23** and as is typically the case when navigating arterial pathways such as coronary arteries.

With reference to FIG. **24**, details of arterial pathways within a heart H in which implantation of an enhanced flexibility stent such as the stent **110***c* are described. The heart H is supplied with blood through a series of arterial pathways which branch off of the aorta AO and which together define arterial pathways for delivery of blood to the heart H. When lesions form in these arterial pathways, it is often desireable to locate radially expandable stents at a point of weakness and then radially expand these stents against the wall of the artery to support the wall of the artery adjacent the lesion so that blood flow through the artery can continue unimpeded.

While it is known to implant stents in primary arterial pathways such as the right coronary artery RCA, left coronary artery LCA, left circumflex artery LCX and left anterior descending artery LADA, certain secondary arterial pathways cannot be easily accessed with prior art stents. Rather, they require a stent with enhanced flexibility such as the stent **110***c* (FIG. **22**).

Such secondary arterial pathways which can benefit from the implantation of an enhanced flexibility surgical stent **110***c* or other enhanced flexibility surgical stents **110**, **110***a*, **110***b*, **110***d* include the AC marginal artery AC, right posterior lateral arteries RPL_1, RPL_2, RPL_3, the diagonal arteries D_1, D_2, D_3 of the left interior descending artery LADA along with the septal artery S and the ramus artery RA and the marginal arteries M_1, M_2, M_3 of the left circumflex artery LCX. These secondary arterial pathways are typically characterized in that they branch in a rather tortuous fashion off of primary arterial pathways and require a small diameter highly flexible stent for location and implantation therein. With enhanced flexibility stents **110**, **110***a*, **110***b*, **110***c*, **110***d* tortuous pathways of lumens such as the secondary arterial pathways shown in FIG. **24** can be accessed and treated.

Moreover, having thus described the invention, it should be apparent that various different modifications could be made to the particular configuration of elements forming the stents **10**, **110**, **210**, **310**, **410** disclosed herein. For instance, while the different embodiments have featured different types and numbers of circumferential elements and axial elements, it is understood that many of these features could be utilized in other embodiments than those where such features are specifically shown. For instance, multi-element junctions such as the junctions **380** could be used to join together adjacent crests **36** of the struts **20** of the stent **10** of the preferred embodiment. Similarly, the stent 10 of the preferred embodiment could be provided with tie bars **50** located in every slot **46**. The preferred embodiment and alternative embodiments described above are provided only by way of example and are not intended to restrict the scope of this invention as claimed.

What is claimed is:

1. An enhanced flexibility radially expandable substantially non-axially contracting surgical stent for implantation into a body lumen, such as an artery, said stent having a generally cylindrical contour both before and after radial expansion thereof, said stent comprising in combination:

at least three circumferential elements, each circumferential element forming an elongate circuit completely circumscribing said cylindrical contour;

each said circumferential element having a wave-like series of bends therein as each said circumferential element circumscribes said cylindrical contour of said stent;

each said wave-like series of bends including a trough and a crest, said trough defining a portion of said circumferential element where said circumferential element is more distant from adjacent said circumferential elements than other portions of said circumferential element, said crest defining a portion of said circumferential element where said circumferential element is closer to adjacent circumferential elements than other portions of said circumferential element;

at least two gaps circumscribing said cylindrical contour of said stent between said at least three circumferential elements;

each one of said gaps having at least one axial element having two extremities and located spanning said gap between a pair of adjacent circumferential elements, said extremities each attached to a different one of said pair of adjacent circumferential elements, joining said pair of circumferential elements together;

at least one of said gaps spanned only by axial elements having each one of said extremities attached to an adjacent one of said circumferential elements at one of said troughs;

at least one of said gaps spanned by at least one axial element having a means to elongate axially when forces applied to said stent cause a central axis of said stent to bend, such that portions of said gap can elongate axially allowing said stent to bend; and

wherein said gaps spanned only by axial elements having each said extremity attached at said troughs alternate

with said gaps spanned by said axial elements having said means to elongate.

2. The enhanced flexibility stent of claim 1 wherein said axial elements which span said gaps with said extremities of said axial elements attached to said circumferential elements at said troughs are linear in form and aligned axially, parallel to said central axis of said stent.

3. The enhanced flexibility stent of claim 1 wherein said gaps include narrow gaps and wide gaps, said wide gaps having a greater width than said narrow gaps, said wide gaps alternating with said narrow gaps, said wide gaps having said axial elements having said means to elongate axially therein and said narrow gaps having said axial elements attached to said circumferential elements at said troughs therein.

4. An enhanced flexibility radially expandable substantially non-axially contracting surgical stent for implantation into a body lumen, such as an artery, said stent having a generally cylindrical contour both before and after radial expansion thereof, said stent comprising in combination:

at least three circumferential elements, each circumferential element forming an elongate circuit completely circumscribing said cylindrical contour;

each said circumferential element having a wave-like series of bends therein as each said circumferential element circumscribes said cylindrical contour of said stent;

each said wave-like series of bends including a trough and a crest, said trough defining a portion of said circumferential element where said circumferential element is more distant from adjacent said circumferential elements than other portions of said circumferential element, said crest defining a portion of said circumferential element where said circumferential element is closer to adjacent circumferential elements than other portions of said circumferential element;

at least two gaps circumscribing said cylindrical contour of said stent between said at least three circumferential elements;

each one of said gaps having at least one axial element having two extremities and located spanning said gap between a pair of adjacent circumferential elements, said extremities each attached to a different one of said pair of adjacent circumferential elements, joining said pair of circumferential elements together;

at least one of said gaps spanned only by axial elements having each one of said extremities attached to an adjacent one of said circumferential elements at one of said troughs;

at least one of said gaps spanned by at least one axial element having a means to elongate axially when forces applied to said stent cause a central axis of said stent to bend, such that portions of said gap can elongate axially allowing said stent to bend;

wherein said means to expand includes said axial element having a left arm attached to one of said circumferential elements at a left end and a right arm attached at a right end to an adjacent one of said circumferential elements, and an elbow attaching said left arm to said right arm, said elbow including means to flex; and

wherein said left arm and said right arm are oriented non-parallel to each other and wherein said elbow is attached to said left arm at an end of said left arm opposite said left end, and said elbow attached to said right arm at an end of said right arm opposite said right end.

5. The enhanced flexibility stent of claim 4 wherein said means to flex of said elbow includes said elbow formed from a common material with said left arm and said right arm and having a width less than a width of said left arm and said right arm.

6. The enhanced flexibility stent of claim 5 wherein said elbow includes a bight on an inner side of said elbow and at least one depression on an outer side of said elbow, said elbow having lesser thickness between said depression and said bight than a thickness of said left arm and said right arm.

7. The enhanced flexibility stent of claim 6 wherein said elbow includes at least two depressions including a left depression at an end elbow adjacent said left arm and a right depression in said elbow on a portion of said elbow adjacent said right arm, said left depression and said right depression spaced from said bight by a width less than a width of said left arm and said right arm.

8. A surgical stent for implantation into a body lumen, said stent having a substantially cylindrical contour and being radially expandable, the stent comprising in combination:

a plurality of circumferential elements, each circumferential element encircling said cylindrical contour of said stent;

at least two of said plurality of circumferential elements having an undulating form including at least one trough and at least one crest as said undulating circumferential elements circumscribe said cylindrical contour of said stent;

at least one axial element located between two adjacent said circumferential elements and attached to one of said adjacent circumferential elements at a first junction and to the other of said circumferential elements at a second junction;

said at least one axial element having a means to elongate axially such that a central axis of said stent is allowed to bend;

wherein said at least one axial element includes a left end adjacent said first junction and a right end adjacent said second junction, said left end including a left arm extending from said left end, said right end including a right arm extending from said right end, and said left arm and said right arm coupled together at a medially located elbow there between, said elbow having a means to flex, such that said left end can be moved away from said right end and said axial element elongates; and

wherein said left arm and said right arm extend linearly non-parallel to each other.

9. A surgical stent for implantation into a body lumen, said stent having a substantially cylindrical contour and being radially expandable, the stent comprising in combination:

a plurality of circumferential elements, each circumferential element encircling said cylindrical contour of said stent;

at least two of said plurality of circumferential elements having an undulating form including at least one trough and at least one crest as said undulating circumferential elements circumscribe said cylindrical contour of said stent;

at least one axial element located between two adjacent said circumferential elements and attached to one of said adjacent circumferential elements at a first junction and to the other of said circumferential elements at a second junction;

said at least one axial element having a means to elongate axially, such that a central axis of said stent is allowed to bend;

wherein said at least one axial element includes a left end adjacent said first junction and a right end adjacent said second junction, said left end including a left arm extending from said left end, said right end including a right arm extending from said right end, and said left arm and said right arm coupled together at an elbow there between, said elbow having a means to flex, such that said left end can be moved away from said right end and said axial element elongates; and

wherein said means to flex includes said elbow having a thickness which is less than a thickness of said left arm and said right arm, said elbow having a sufficiently narrow thickness to allow said elbow to bend, such that said left arm and said right arm can be flexed toward and away from each other with said left end and said right end being drawn closer to and further away from each other.

10. A radially expandable surgical stent having a generally cylindrical contour, comprising in combination:

a plurality of circumferential elements circumscribing the cylindrical contour of said stent, said circumferential elements including means to radially expand;

at least one axial element between each adjacent pair of said circumferential elements; and

at least one of said axial elements being an adjustable length axial element, said adjustable length axial element including:

a first arm attached to one circumferential element of the pair of circumferential elements at a first end;

a second arm attached to a second circumferential element of the pair of circumferential elements at a second end, said second arm not parallel with said first arm; and

a medially located elbow joining said first arm to said second arm, said elbow including means to flex causing said arms to pivot relative to each other and causing the pair of circumferential elements to move relative to each other.

11. The stent of claim **10** wherein said means to flex of said elbow includes said elbow having a lesser thickness than a thickness of said arms, such that said elbow exhibits a greater flexibility than said arms.

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